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The performance of farm tractors as reported by CAN-BUS measures

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Abstract
Tractors and agricultural machinery have been designed specifically for land preparation, tillage, and other agricultural operation's tasks. Tractors are the primary source of power in farms and fields. Thus, to obtain the optimum output from them, proper management and utilization is needed. Agricultural machinery performance has been studied over the past three decades and optimum results have been obtained for different kinds of agricultural machinery. In general, the evaluation of agricultural machinery using traditional methods is problematic as they are time consuming and labor intensive. Moreover, by using the common evaluation methods it is typically difficult to obtain accurate and instant results. Accurate measurements of field performance parameters are required for monitoring machinery performance and management decisions. Recently, the improvement in the electronics technology has made field operational management easier to monitor. Controller Area Network (CAN) Bus technology is being used as a communication system in tractors and allows connections between Electrical Control Units (ECU). CAN Bus technology broadcast unique electronic messages which contain continuously updated information about the engine, power train, equipment, power take off, hydraulic system, and other parts of the machines. To evaluate the performance of agricultural machinery, there is no longer a need for myriad measurement instruments producing widely varying output to individually measuring fuel consumption for each speed, gear shift and the whole operation. As a result, this study was conducted to evaluate tractor performance by CAN Bus technology as a simple to use, easy to install, high speed data collection, and convenient to retrieve the stored data. These techniques allow for substantial saving of money and time, reducing our workload and eliminating training necessary for specialized measurement tools.

Keywords
CAN Bus, Field efficiency, Fuel consumption, Tractor Slippage percentage

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THE PERFORMANCE OF FARM TRACTORS AS REPORTED BY CAN-BUS MESSAGES

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ABSTRACT. *Tractors and agricultural machinery have been designed specifically for land preparation, tillage, and other agricultural operation's tasks. Tractors are the primary source of power in farms and fields. Thus, to obtain the optimum output from them, proper management and utilization is needed. Agricultural machinery performance has been studied over the past three decades and optimum results have been obtained for different kinds of agricultural machinery. In general, the evaluation of agricultural machinery using traditional methods is problematic as they are time consuming and labor intensive. Moreover, by using the common evaluation methods it is typically difficult to obtain accurate and instant results. Accurate measurements of field performance parameters are required for monitoring machinery performance and management decisions. Recently, the improvement in the electronics technology has made field operational management easier to monitor. Controller Area Network (CAN) Bus technology is being used as a communication system in tractors and allows connections between Electrical Control Units (ECU). CAN Bus technology broadcast unique electronic messages which contain continuously updated information about the engine, power train, equipment, power take off, hydraulic system, and other parts of the machines. To evaluate the performance of agricultural machinery, there is no longer a need for myriad measurement instruments producing widely varying output to individually measuring fuel consumption for each speed, gear shift and the whole operation. As a result, this study was conducted to evaluate tractor performance by CAN Bus technology as a simple to use, easy to install, high speed data collection, and convenient to retrieve the stored data. These techniques allow for substantial saving of money and time, reducing our workload and eliminating training necessary for specialized measurement tools.*

Keywords. *CAN Bus, Field efficiency, Fuel consumption , Tractor Slippage percentage*

1.0 Introduction

Agricultural machinery plays an important role in improving performance, productivity, and reducing costs of agricultural operations. During the recent decades, agricultural machines have been developed to reduce labor costs as well as improve the timeliness of field operations (Schäfer-Landefeld et al., 2004). Moreover, agricultural machine efficiencies have a significant effect on the yield which in turn impact the overall cost of production (Pitla et al., 2014).

Tillage is among one of the most important operations in agriculture. It is defined as “the changing of soil condition for the enhancement of crop production” (ASAE Standards, 2009). Tilling the soil produces ideal soil conditions by improving the relationship between air and water for crop growth (Osunbitan et al. 2005, Busscher and Bauer, 2003, Gill and Vander berg, 1967). However, many studies show tillage consumes at least half of the engine power to operate the implement and around 30 percent of the total power consumption in the agricultural operation (CAST, 1984), This has led many farmers to become more concerned about tillage and seek new method to reach optimum production by substituting human power with mechanical power (Ahaneku et al., 2011). Tillage can be classified as primary or secondary. Primary tillage constitutes the initial major soil working operation. It is normally designed to reduce soil strength, cover plant materials, and rearranges aggregates. While, secondary tillage is a shallower depth than primary tillage implements to provide additional pulverization, mix pesticides, and fertilizers into the soil, level and firm the final secondary tillage operation(ASABE Standards, 2005). The best examples of secondary tillage is a field cultivator for seedbed preparation, weed eradication, or fallow cultivation subsequent to some form of primary tillage. (ASABE Standards, 2009).Hence, studying field parameters during tillage help the operator to manage their machines.

Tractors and agricultural machinery have been designed as a standard for land preparation, tillage, and other agricultural operational tasks. Tractors are the primary source to provide a mechanical power to farms and fields (Kepner et al., 1978). Thus, to obtain the optimum output from them, good management and utilization should be applied. Tractor performance has been studied over the past three decades and optimum results could be obtained for different agricultural machinery (McNeill et al., 2008). It is always desired to have the most power converted from the engine to traction power which results in lower energy loss during the agricultural operation (Ahaneku et al., 2011). The study conducted by Sabanci (1997) found that 12.0 to 18.0% of the engine power was consumed before starting the operation. In addition, another 20.0 to 40.0% of power is lost between the axles and the ground (Mowitz and Finck, 1987). Improper selection of tractor size can cause excessive operating costs. So, knowing the parameters that affecting efficiency would improve the performance of an agricultural machinery (Summer and Williams, 2007).

Moreover, despite the type of soil condition, and tire design, other important parameters that affect the tractor performance include implement size, practical speed, and depth of operation. These parameters can be easily be managed and controlled by the operators to obtain the optimum performance. In addition, proper tire inflation pressure and setting up ballasting weight and are essential for evaluating and managing the performance. According to Sumer and Sabanci, (2005), in order to obtain the best performance with least cost, proper ballasting, and correct tire inflation must be adjusted. Improper adjusting leads to fuel waste, tire wear, and drive train damages, and decrease productivity and efficiency (McNeill, 2008). Wulfsohn and Way (2009) found that ballasting and tire inflation pressure played a significant role in tractor fuel consumption and tractive performance. A tractive efficiency improvement of about 4% to 7% was obtained while using correct ballast with low-correct tire inflation pressure as compared to overinflated tires (Zoz and Turner, 1994). Likewise, as reported by Lancas et al. (1996), 18% to 20% of fuel was saved when they used low-correct inflation pressure with regard to axle load.

Furthermore, the main performance indicators in tillage operations are fuel consumption, slippage percentage, engine percent load, engine cooling systems and fuel temperature. Fuel consumption is considered most important factor for research in agricultural operations, testing and assessing the performance of the machines. According to Hanna (2001) and Thakare and Deshmukh (2009), fuel consumption is affected by a numbers of factors such as soil types and moisture, the users, tractor design (two wheels or four wheels), tractor size, equipment width, working depth and speed of operation. Likewise, mentioned by Bukhari and Baloch (1982) fuel consumption depends on different variables such as width and depth of cut, and speed and kind of operation. Fuel consumption can be measured with either a direct or indirect method. The direct method is accomplished by measuring the level of fuel in the tank before and after the operation and indirect is determined by using a graduated cylinder located between the tank and the fuel injection pump to measure the consumed fuel (Natsis et al., 1999). Moreover, field efficiency is the ratio of effective field capacity to theoretical field capacity, expressed in percent. Further, it is the comparison between the amount of power consumed by the machine to the amount that should be consumed (ASABE Standards, 2011).

In addition, to measure and monitor the mechanization unit performance, enumerated systems have been developed to determine tractor performance monitoring and optimization (TPMO). However, the majority of these systems were not fully adequate. The best example of this system is Controller Area Network (CAN) Bus technology developed by Mercedes Corporation (Voss, 2005). This technology is a communication system in vehicles and allows connections between multiple Electrical Control Units (ECU). Currently, the improvement in electronics technology has made field operations management easier to monitor. This new CAN Bus technique is becoming the most widely used applications in agriculture to help farmers determine and improve field efficiency while decreasing equipment costs using the data obtained from tractors (Darr, 2012). CAN messages depend on the broadcast system and can filter the required messages. These messages are continuously updating information about the engine, power train, equipment, power take off, and hydraulic system (Darr, 2012).

According to The United Nations, the Gross Domestic Production (GDP) for some of Middle East countries has declared and has been moved towards the negative annual growth. This degradation in agricultural production system address the unique challenges to increase agricultural machinery performance. Efficiency and accuracy of works are best required solution in order to reduce the shortfall in food production system and as an essential element to maximizing machinery performance. The fact that there is a limited progress in agricultural mechanization sector impact the agricultural production in a significant portion. Testing and evaluation of agriculture machinery using updated technologies and techniques is a key contribution in farm production. The technology like CAN bus will help to increase efficiency by monitoring machine performance and reduce production costs in the Middle East region.

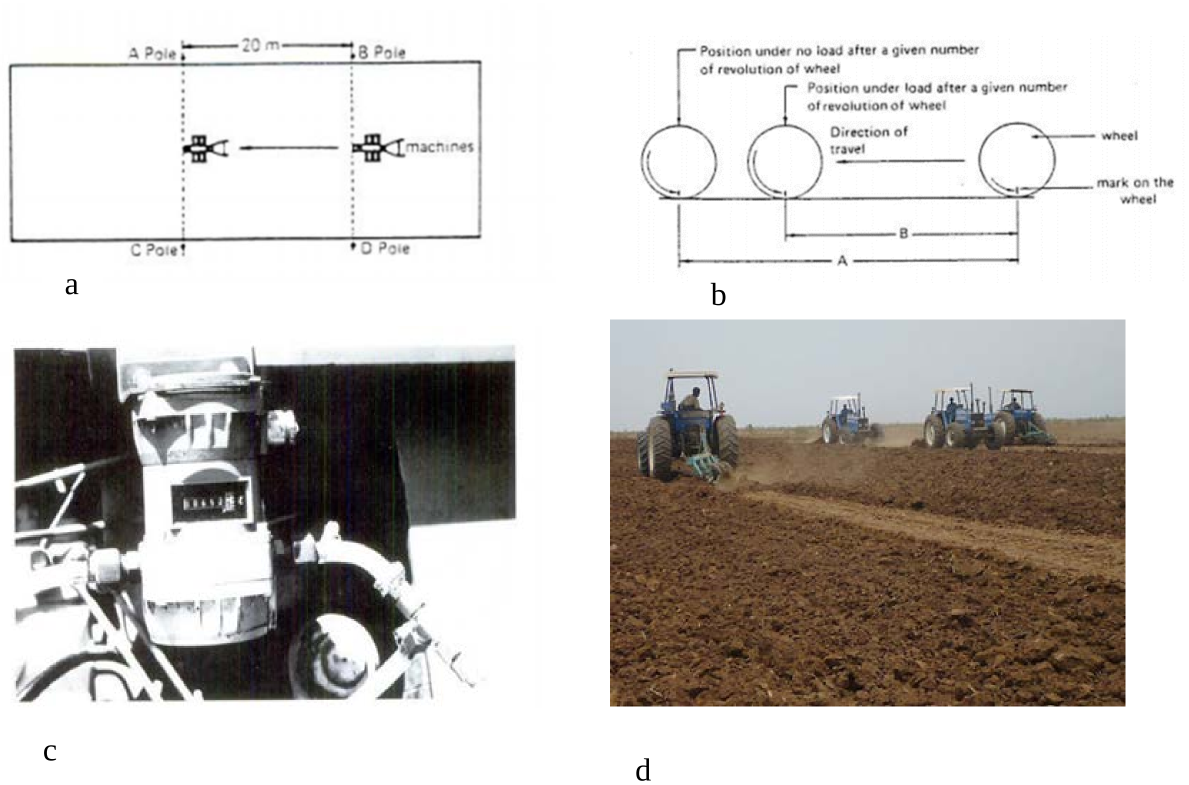

Figure 1. Traditional method

(a) Measuring speed (b) Measuring Slip percent (c) Fuel consumption measurement

(d) Traditional cultivation (ICRC, 2011). .

Objectives

The objective of this study was to demonstrate the capabilities of a CAN bus based evaluation system for quantifying key performance indicators for an agricultural tillage operation. Results will be demonstrated through a case study analysis of field cultivation under multiple tractor and implement configurations.

2.0 Materials and methods

Field Equipment and Data Collection

This study was conducted in a field in Ames, Iowa, United States (March 2016). The field was approximately 41 hectares and the previous crop was soybeans (Figure 2a). The field soil type was Webster clay loam with 0.00 to 2.0% slopes. CAN bus data were obtained from the International Standard Organization (ISO) diagnostic port of a four-wheel drive (4WD) tractor (John Deere 9430) to collect and monitor the performance of the unit. The tractor static weight distribution was 53.20% front and 46.45% rear and all tires were Firestone Dual 710/70 R42. The implement used an all testing was 15.54 m (51 ft) wide field cultivator (John Deere 2210) which is representative of the tillage implements most commonly used for seedbed preparation in the region (Figure 2b).

(a) (b)

Figure 2. (a) A 41 hectare Soybean field (b) John Deere (9430) and field cultivator.

A CAN bus analyzer (Vector VN 1610) was used to collect messages from the tractor using a laptop through Universal Serial Bus (USB). Data were logged in an American Standard Code for Information (ASCI) file in real –time during field operations. In addition, a backup data set was recorded by using Vector (GL1000) data logger for backup.

(a) (b)

Figure 3. (a) VN1610 Vector CAN Card (b) 9 Pins diagnostic to serial port

The tractor bus was configured at 250 kb/sec and messages were recorded in hexadecimal format. The Society of Automotive Engineering (SAE) J1939 database protocol was used to decode the structure of the CAN message into PGN and data byte values. After collection the raw ASCII CAN logs were uploaded to a Structured Query Language (SQL) database for data interrogation and management. Figure 3 demonstrate the Parameter Group Number (PGN) used for Engine Fuel Rate was PGN 0xFEF2 and for Engine Speed was PGN 0xF004. Moreover, the tractor was connected with John Deere StarFire 3000 GPS receiver to provide geospatial position and GPS based speed information during the test. The field key performance indicators of the combination unit are fuel rate, slip percentage, and effective field capacity.

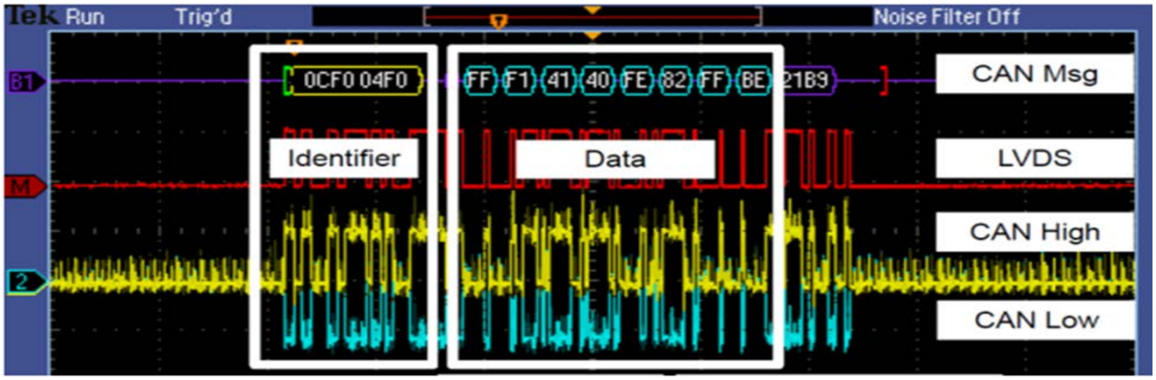

Figure 4. Message identifier and Parameter Group Number (PGN) Message (Darr, 2012)

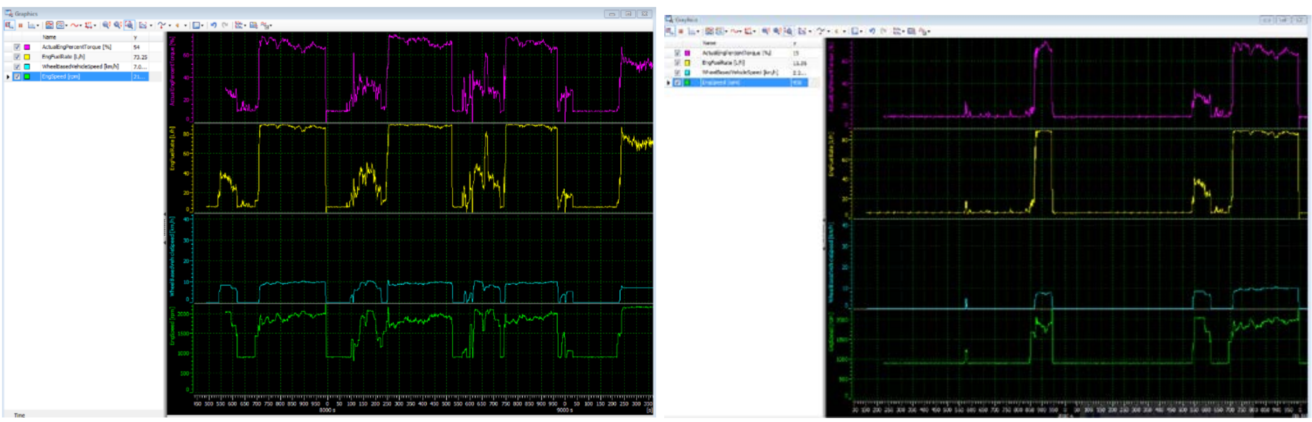

Figure 5. CAN Bus signals recorded during the test

2.1 Key Performance Indicators

Field capacity (FC) is the rate of a machine's performance that could be measured depending on the type of the machine as either ha/h or kg/h. The field capacity is an important parameter to determine the machine selection and cost evaluation. Field efficiency can be classified as the ratio of Effetive field capacity (EFC) to Theoretical field capacity (TCF). The TFC is described as the maximum rate of machine performance achieved by forward speed and complete implement width expressed as ha/h (Equation 1). (ASABE Standards, 2006).

$$\text{TFC} = \frac{(\text{W} * \text{S})}{10} \tag{1}$$

Where

TFC = Theoretical Field Capacity (ha/h).

W = Implement width (m)

S = speed (km/h)

Effective Field Capacity (EFC) is the actual rate of machine performance in regard to field efficiency, actual working width, and practical speed expressed as ha/h. The EFC can be determined using equation 2. (ASABE Standards, 2006).

$$\text{EFC} = \text{TFC} * \text{Ef} = \frac{\text{S} * \text{W} * \text{Ef}}{10 * 1000} \tag{2}$$

Where

EFC = Effective Field Capacity (ha/h)

S = Practical speed (km/h)

W = Rated width of implement (m)

Ef = Field efficiency (%)

Field Efficiency (FE) is the ratio of the effective field capacity to theoretical field capacity. Field efficiency can be improved by reducing lost time during operation, such as filling, unloading, turning, blocking, checking, repairing, and resting (Helsel, 2015). FE can be calculated using equation (3) (ASABE Standards, 2006).

2.2 Experimental Design

The study was arranged in Randomized Complete Block Design (RCBD) with four factors, two levels of each factor (explanatory variable), and three blocks per treatment. The field designated for the combination of tractor and field cultivator to perform the secondary tillage was divided into three blocks with 16 strips (treatment) per block for a total of 48 strips (one strip per treatment). The four factors are tractor weight, tractor tire inflation pressure, tillage depth, and percentage of engine power usage. The tire inflation pressure were set for 21- 22 psi (all tires) in the first level and 10- 11 psi for the front tire and 7-8 Psi for the rear tire in the second treatment level. Two levels of tractor weight was used including the static weight (19750 kg) and 2120 kg added weight (tractor weight). Tillage depth treatment included 7.62 cm and 12.7 cm respectively and the engine power was controlled at two levels of 100% engine power usage and 70% engine power usage as determined by the transmission gear selection. Each treatment was a unique possible combination of each level of the four factors. The data were analyzed using SAS version 9.4.

3.0 Results and Discussion

Table 1 show the descriptive statistics of the results of fuel consumption rate, slippage percentage, Effective Field Capacity (ha/h).

3.1Fuel consumption rate

The fuel consumption of the tractor was determined for standard weight and added weight in relation to engine power, tillage depth and the tire inflation pressure. The results are shown in Table 1 and Figure 6. The results show there was a significant difference ($P<0.05$) due to engine power, tillage depth, tire inflation pressure and the interaction between tillage depth and engine power. After adjusting for multiple comparison, there was no significant difference ($P<0.05$) between depth 7.62 and 12.7 cm (86.21 L/h and 87.05 L/h respectively) on maximum power. In contrast, there was a significant difference observed at low power for depth 7.62 and 12.7 cm as shown in Table 1.

Table 1. Descriptive data for fuel rate, slippage percentage, and effective field capacity.

Weight(Kg)	Tire Pressure (Psi)	Cult. Depth (cm)	Power	FuelRate L/hr	S%	EFC ha/hr
19750	21.5	7.62	Max Power	88.07±0.40	13.29±0.76	9.89±0.12
			70% Power	86.91±0.60	11.97±0.76	7.65±0.12
		12.7	Max Power	87.25±0.60	24.11±0.76	7.00±0.12
			70% Power	75.80±0.60	24.24±0.76	5.83±0.12
	10 & 7	7.62	Max Power	86.03±0.60	10.95±0.76	10.47±0.12
			70% Power	67.04±0.60	10.16±0.76	7.83±0.12
		12.7	Max Power	87.00±0.60	20.09±0.76	7.50±0.12
			70% Power	74.47±0.60	20.58±0.76	6.15±0.12
21000	21.5	7.62	Max Power	86.41±0.60	11.93±0.76	10.23±0.12
			70% Power	67.50±0.60	10.41±0.76	7.81±0.12
		12.7	Max Power	87.82±0.60	19.53±0.76	7.55±0.12
			70% Power	75.25±0.60	19.80±0.76	6.18±0.12
	10 & 7	7.62	Max Power	85.50±0.60	9.36±0.76	10.82±0.12
			70% Power	67.01±0.60	8.59±0.76	8.00±0.12
		12.7	Max Power	86.16±0.60	14.30±0.76	8.26±0.12
			70% Power	73.10±0.060	14.82±0.76	6.69±0.12

Additionally, a significance difference within depth was observed between maximum and 70% power, for instance at depth 7.62 cm, the fuel rate for the maximum power was 86.21 L/h while 70% power was 67.58 L/h. Increasing tillage depth associated with increasing soil disturbed volume and that leads to increase tractor load and fuel consumption to pull the implement (Moitzi et al., 2006 and Flipovic et al., 2004).

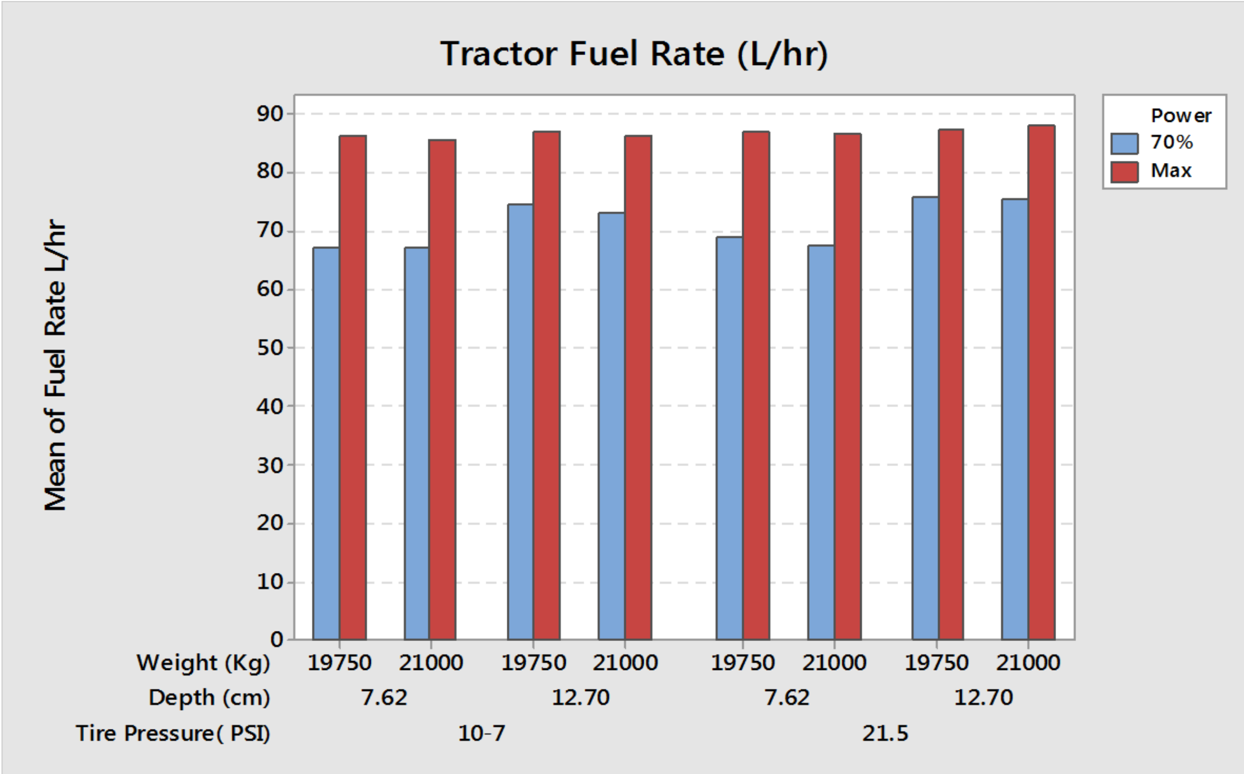

Figure 6. Mean fuel rate of tractor with standard and added weight.

In addition, at the standard weight the maximum fuel consumption (87.24 L/h) was observed at maximum power at maximum depth (12.7 cm) and maximum tire pressure. Likewise, for the same weight, the low fuel consumption (67.04 L/h) was observed at 70% power in low depth (7.62 cm) at low tire inflation pressure. Moreover, in adding weight the maximum fuel rate was observed at maximum power and higher depth (12.7 cm) at high tire inflation pressure and low fuel consumption was observed at low power in low depth (7.62 cm) and low tire inflation pressure as shown in Table 1.

3.2 Slippage Percentage

The slippage percentage is the key indicator of the efficiency of the tractor operation. It is used as a measure to indicate whether the right combination of tire inflation pressure, overall tractor weight, and operating speed are resulting into optimal fuel usage (NSW, 2013). The results show the slippage percentage range from 8.59% to 24.24%. The high slippage percentage (24.24%) in standard weight was observed at a maximum tire inflation pressure at high tillage depth (12.7 cm) and 70% power. The result also shows that the engine power usage is not significant on fuel rate consumption. Additionally, the higher slippage percentage occurred at lower power usage and higher tillage depth. Moreover, for the added weight, the highest slippage percentage (19.80%) was observed at maximum tire inflation pressure, higher depth (12.7 cm) and low power (70%). While the lowest slippage percentage was observed at low tire pressure, low tillage depth and 70% power usage shown in Table 1 and Figure 7. According to Raheman and Jha (2006), the optimal slippage percentage lies between 8% and 15%. Increasing the tillage depth from shallow to deep increases the slip percent for low engine power and maximum engine power by 46% and 71% due to the increases in load of extra soil disturbed volume (Al-Ani et al., 2005).

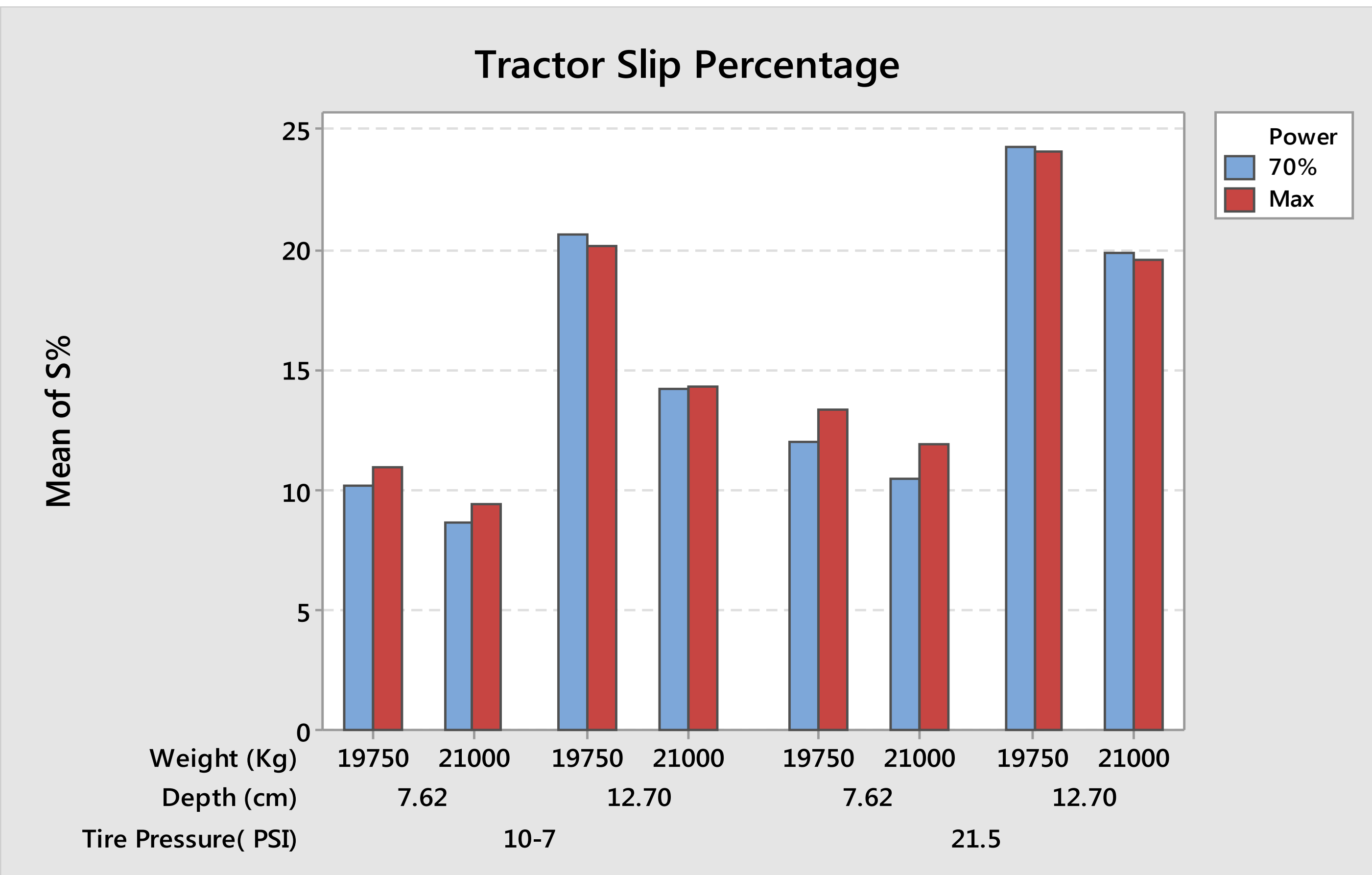

Figure 7. Mean slippage percentage of tractor with standard and added weight.

3.3 Effective Field Capacity

Effective field capacity is the actual productivity of a field machine considering field efficiency and field speed in addition to the effective working width of an implement (Roberson, 2008). Table 1 shows descriptive values of effective field capacity. A significant difference was observed in weight (standard and added), tire inflation pressure (low and high), tillage depth (7.62 and 12.7 cm), and engine usage power (70% and 100%). Also, significant difference was observed on the interaction between depth and engine usage power (depth * power). The effective field capacity for standard weight range from 5.83 ha/ h to 10.47 ha/h. On the other hand, the effective field capacity for added weight was between 6.18 ha/h to 10.82 ha/h. Overall, the highest effective field capacity (10.82 ha/h) was observed at added weight, low tire inflation pressure, shallow tillage depth (7.62 cm) and maximum engine usage power. Likewise, the lowest effective field capacity was observed in standard weight, higher tire inflation pressure, deep tillage depth and 70% engine power usage as shown in Figure 8.

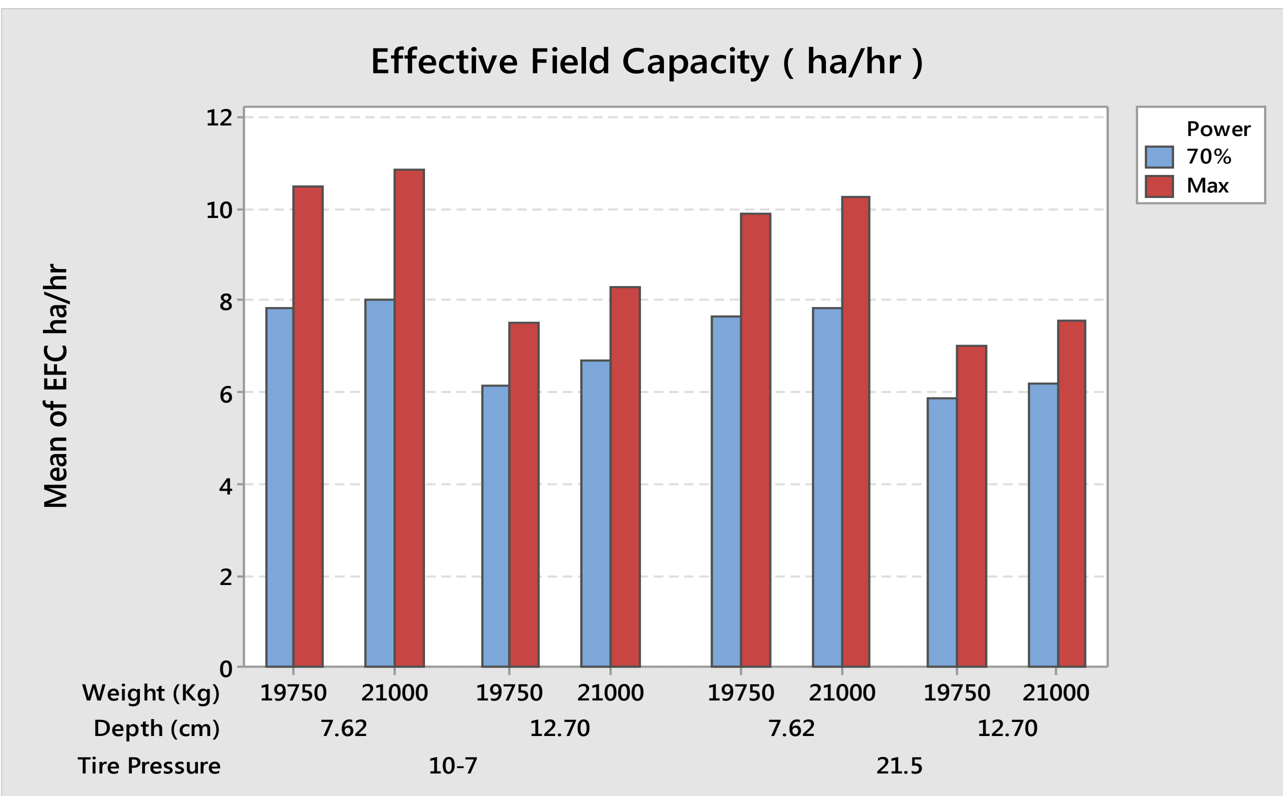

Figure 8. Mean effective field capacity of tractor with standard and added weight.

4.0 Conclusions

Field performance parameters are used to monitor agricultural machinery performance. The technique like CAN Bus enable operators to monitor agricultural machinery such as tractor in the field operation. In this study, CAN Bust was used to collect data and measure the tractor implement performance parameters such as fuel rate, wheel based speed, and GPS speed. The use of CAN Bus technology indicates reliable future use to improve and evaluate agricultural machinery. Changing input variables impact performance parameters. The input variables examined were total tractor weight, tire inflation pressure, tillage depth, and engine power usage. There was no significant difference between standard weight and added in many parameters assessed. The study shows the minimum fuel consumption rate and wheel slip percentage with the utmost field efficiency occurred when a tractor-implement at 70% engine usage power for either low or high tillage depth and at an optimum tire inflation pressure when extra weight were added. Thus, operator needs to choose a proper set up to achieve optimum performance and correct decision.

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